



Artificial Intelligence and Wearable Sensor-Based Gait Analysis in Chronic Ankle Instability: A Scoping Review

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Abstract

Background: Chronic ankle instability (CAI) frequently arises from recurrent ankle sprains, resulting in persistent pain, weakness, and altered gait patterns that impair mobility and quality of life. Wearable sensors such as inertial measurement units (IMUs, accelerometers, gyroscopes, and smart insoles enable real-time gait monitoring outside clinical settings. Artificial intelligence (AI) techniques enhance the detection of these abnormalities with high accuracy and enable objective, continuous, and real-world gait analysis, offering new opportunities for early detection and rehabilitation monitoring.

Objective: This scoping review maps the extent, nature, and evidence on AI-driven analysis of gait data from wearable sensors in CAI assessment, emphasising clinical and physiotherapy applications, key trends, gaps, and future directions to map and summarise current evidence on the use of AI methods combined with wearable sensor-based gait analysis in individuals with chronic ankle instability.

Results: Emerging studies demonstrate AI models achieving over 90% accuracy in classifying CAI gait deviations using IMU and shoe-integrated sensors, capturing spatiotemporal asymmetries and joint kinematics. ML excels in joint impairment differentiation, while deep learning aids rehabilitation prediction. Physiotherapy relevance includes objective progress tracking; however, studies are limited to small cohorts, with gaps in longitudinal validation, diverse populations, and unsupervised learning.

Conclusion: Wearable integrations offer promising, portable tools for CAI gait assessment and physiotherapy, but larger trials and standardised protocols are needed to bridge gaps and guide clinical adoption.

Keywords: Chronic ankle instability, gait analysis, wearable sensors, artificial intelligence, machine learning, inertial measurement units, physiotherapy.

1. Introduction

Gait analysis is an essential tool for comprehending human movement. It guides rehabilitation efforts and aids in the identification of functional problems. Artificial intelligence (AI) and wearable sensor have made it simpler to evaluate gait thanks to recent technological developments. These advancements have improved gait assessment, precision, usability, and real time application in both clinical and daily contexts. Wearable sensor and AI tool enable thorough biomechanical evaluations and ongoing monitoring. Early diagnosis and individualized treatment plans result from this. According to recent studies AI and wearable sensor-based gait

analysis can successfully deduce musculoskeletal disorders like osteopenia and sarcopenia in daily life. This emphasizes how useful these technologies are for patient monitoring and clinical decision making. Furthermore, through a comprehensive physiotherapy approach,² advanced motion capture systems such as X Sens have improved outcomes for people with chronic ankle instability CAI. Reduced proprioception, altered gait mechanics, and recurrent ankle sprains are common symptoms of chronic ankle instability. In real-world scenarios, subtle gait changes are frequently overlooked by conventional assessment techniques. In this sense, wearable sensor



technologies and AI -based gait analysis offer a more sensitive and objective method of identifying CAI - related problems.

1.1. Background

Machine learning and deep learning models have advanced the application of artificial intelligence in gait analysis. By improving gait datasets and addressing data shortages, methods such as DAGAN-based gait feature enhancement have been used to increase the accuracy of detecting ankle instability. Additionally, smart shoe sensor systems enable real-time evaluations and continuous patient monitoring for individuals with chronic ankle instability, which support improved rehabilitation planning. Gathering gait data outside of laboratory settings is made easier by wearable sensor technologies including pressure sensors, smart shoes and inertial measurement units (IMUs). These technologies provide ecological validity by capturing gait patterns in common place settings. According to research on gait pattern analysis for early neuromuscular problem diagnosis, wearable sensor and artificial can successfully identify aberrant movement patterns early on, improving clinical outcomes (5). In order to increase the accuracy and clinical significance of gait analysis, wearable sensor data is increasingly being combined with machine learning techniques such as support vector machines, neural networks, and deep learning models, according to systemic reviews of recent research (6,7). AI -driven gait analysis is becoming more popular as a reliable technique for assessing functional deficits and directing therapy for neurological and musculoskeletal disorders as a result of these advancements. Despite these developments, more research into wearable sensor – based gait analysis and artificial intelligence is required, particularly for chronic ankle instability. In order to map current data, pinpoint research gaps, and provide a comprehensive grasp of the most common approaches, technology and therapeutic applications in this field, scoping review is crucial.

1.2. Method

In order to map the available data on the use of wearable sensor- based gait analysis in conjunction

with artificial intelligence (AI) in people with chronic ankle instability (CAI), this study was carried out as a scoping review. The study setting sampling strategy, sampling size were irrelevant because it was scoping review. Instead of soliciting individuals, the emphasis was on methodically locating and summarizing pertinent literature. This study was conducted as a scoping review to map available data on the use of wearable sensor-based gait analysis in conjunction with artificial intelligence (AI) in individual with chronic ankle instability (CAI). The study environment, sampling strategy, and sample size were not applicable because this was a scoping review. Instead of asking people, the emphasis was on meticulously locating and summarizing pertinent information. Several electronic databases, including PubMed, Scopus, Web of Science, Google Scholar and Science Direct, were searched for relevant literature. The search covered full – text papers published in English between 2018 and 2024. Among the pertinent terms discovered were wearable sensors, gait analysis, artificial intelligence, machine learning, inertial measurement unit, chronic ankle instability, and physiotherapy. Boolean operators (AND, OR) were used to combine and refine search phrases for the optimal retrieval of pertinent papers. Studies that employed AI or machine learning approaches, included subjects with a diagnosis of CAI, and used wearable sensors (such as INUs, accelerometer gyroscopes, or smart insoles) for gait analysis were included. We only considered full – text English – language papers that discussed gait metrics such as kinematics and spatiotemporal variables. Studies that addressed acute ankle injuries, did not use wearable sensors or AI-based analysis, were review articles, editorials, conference abstracts without full text, or were published in languages other than English were all disqualified. Before beginning the review, Yenepoya Deemed to be University's Institutional Ethics Committee and SRB granted ethical approval.

2. Results and Discussion

2.1. Results

Chronic ankle instability (CAI)[1], which results in

pain and altered walking patterns, is analyzed using wearable sensors and artificial intelligence (AI). Outside of clinics, real-time monitoring is made possible by gadgets like smart insoles and IMUs. AI facilitates better rehabilitation planning and increases detection accuracy. Research indicates that gait deviations[2] can be identified with high accuracy. Additionally, it aids physiotherapists in objectively monitoring patient progress. However, usage of variable sensor and lack of consistency causes the obstacle. This study clears multiple questions but more study is required for its further investigation and usage in clinical setup[3].

2.2.Discussion

The effect of wearable sensor-based gait analysis and artificial intelligence on chronic ankle instability were assessed in the current study. With a focus on its application in chronic ankle instability (CAI). The current scoping review looks at the available data on the combination of wearable[4] sensor-based gait analysis and artificial intelligence (AI). The review studies show a move away from conventional observational gait assessment and toward real time, data-driven, patient-specific analysis techniques. The growing use of wearable sensor systems is a recurring theme in the literature. Such as shoe-integrated sensors and inertial measurements units (IMUs), to record gait parameters in practical environments. According to research on intelligence diagnosis systems for CAI, these sensors can continuously track kinematic and spatiotemporal[5] wearable, enabling the early identification of instability patterns that might not be apparent during a clinical examination. This is in line with research on shoe -integrated sensor systems, which demonstrate their capacity to offer impartial and ecologically sound data for monitoring rehabilitation and diagnosis. For handling massive volumes of gait data, artificial intelligence methods like machine learning and deep learning models are essential for instance, it has been demonstrated that data augmentation methods like DAGAN (data augmentation generative adversarial networks) enhance gait future datasets, increasing the precision and resilience of ankle instability detection model. In

a similar vein, explainable AI approaches increase model transparency, which helps clinician better understand decision -making procedure and increases confidence in AI-based diagnostic instrument. The application of state of the art technology facilitates the integration of AI into physiotherapy practice motion capture tools, like Xsens gait analysis kinematic data, which can be utilized to oversee customized rehabilitation initiatives when combined with artificial intelligence algorithms investigate shows that by focusing on specific neuromuscular deficiencies and abnormalities[6] of gait such all-encompassing physiotherapy techniques can significantly enhance functional results in those who have persistent ankle instability. Studies on AI-based gait analysis suggest that it may have broader clinical applications outside of CAI neuromuscular conditions and illnesses such as sarcopenia and osteopenia. These results demonstrate wearable sensors capacity to identify minute biomechanical alterations linked to neurological and musculoskeletal disorders, suggesting that comparable techniques can be successfully used with CAI population. Machine learning models, both supervised, and unsupervised, are increasingly being used for classification[7], prediction, and risk assessment, according to systematic reviews of current gait analysis trends. Additionally, these reviews draw focus on problems that continue to be significant barriers to widespread clinical implementation, such as small sample size, data heterogeneity, and the need for standardized procedures. Despite positive advancements, the reviewed studies exhibit several limitations. Ecological validity is diminished by the fact that many studies rely on controlled laboratory setting rather than free-living environment. Cross-study comparisons are further complicated by variations in sensor placement, data processing techniques, and outcomes measures. The capacity to assess the long-term effectiveness of AI-Guided interventions in CAI management is further hampered by the dearth of extensive longitudinal studies.



Conclusion

In conclusion, the diagnosis and treatment of chronic ankle instability may be revolutionized by combining wearable sensor – based gait analysis with artificial intelligence. These tools provide precise ongoing, and in partial gait pattern monitoring, which supports early diagnosis and individualized treatment plans. However additional study focused on standardization, practical use, and long- term therapeutic outcomes is required to fully realize their promise in everyday physiotherapy practice.

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